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MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1991

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries eleventh annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1991, eighty-seven sampling trips were made aboard commercial lobster vessels. A total of 45,026 lobster was sampled from 16,366 trap hauls. The catch rate of marketable lobster, 0.795 lobster per trap, was only 3.8% lower than the 1990 index, 0.826. The proportion of females ovigerous, 9.8%, was significantly lower than in the previous year (10.9%). Coastwide fishing mortality estimates reached their highest level in the eleven-year study period and exploitation rates were similar to 1990 data. Mean carapace length of marketable lobster, 88.7 mm, was comparable to mean size measured the previous year, but the mean size of egg-bearing females declined in all regions. The percentage of culls sampled, 18.1%, was similar to the 1990 index. As observed in previous years, less than 1% of the lobster sampled from traps were dead; however, trap mortality in Buzzards Bay, 1.74%, was abnormally elevated.

Analysis of size frequency change relative to the 1988-89 gauge increase showed stabilization of market categories in the last three years. Only minor changes in the size frequencies of all lobster sampled were evident and, in 1991 reflect compliance with regulatory change in the minimum escape vent size.

Fishing mortality rates (F) were calculated for southern Gulf of Maine, outer Cape Cod, and Buzzards Bay using respective sea sampling size frequencies weighted by monthly landings from each region. Cohort analyses were performed by year, 1981-1991, and for combined years. Estimates of F for southern Gulf of Maine and outer Cape Cod were higher in recent years. Sensitivity of cohort analysis to variation of input parameters was assessed. Growth rate had the strongest effect, maximum length had moderate effect, and total and natural mortality had relatively little effect on estimates of F.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) eleventh annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling-survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1991 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1991 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations were recorded from LORAN and plotted on nautical charts. Depth information was then acquired from the charts as a coastwide standard to avoid variability from tidal fluctuations.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred for analysis to the National Marine Fisheries Service's Digital Equipment Corporation VAX-11/780 computer system at Wood Hole Oceanographic Institution. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

The Kolmogorov-Smirnov two sample test and Mann-Whitney U/Wilcoxon W test were used to determine the significance of year to year variation in parameters.

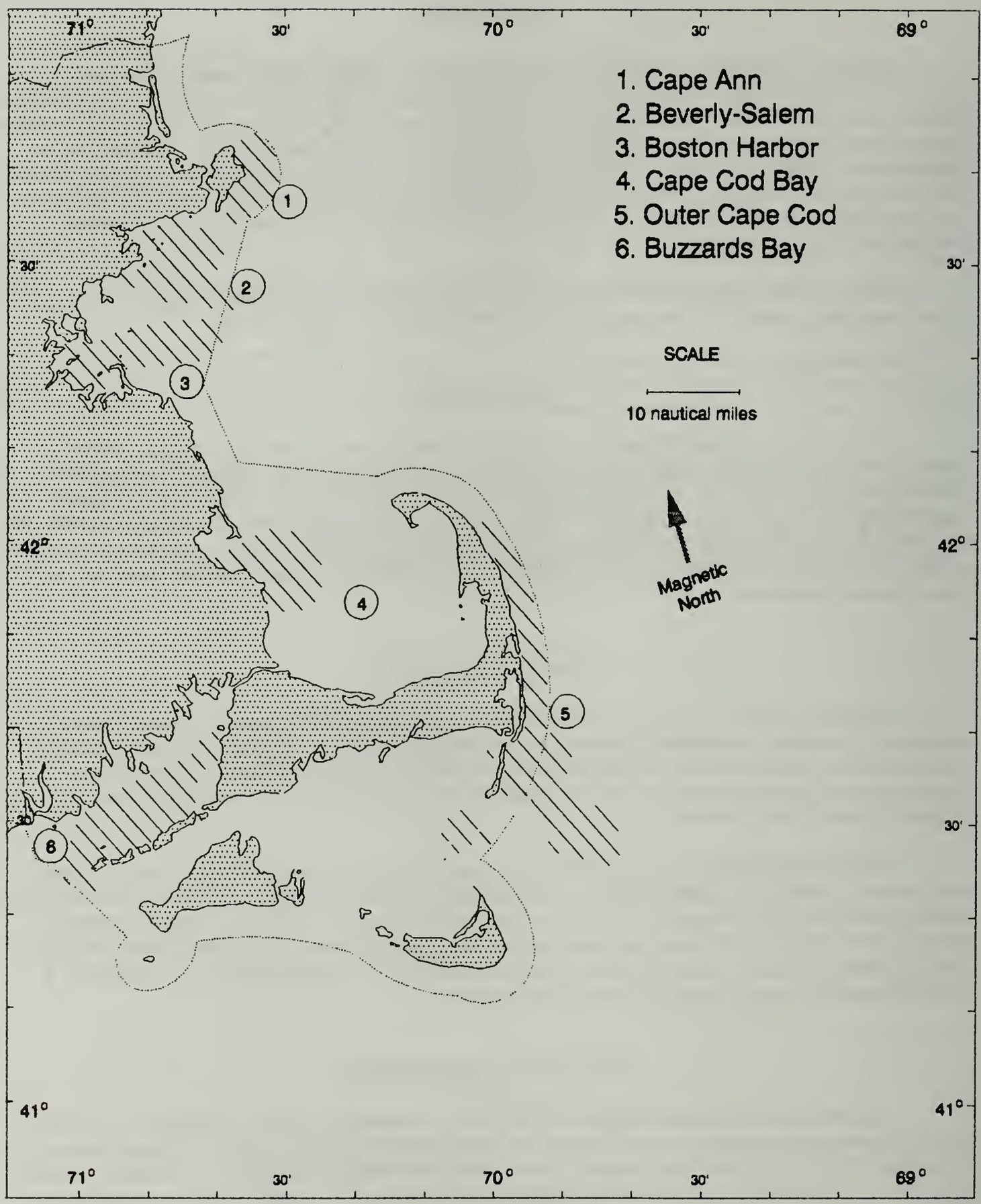

Figure 1. Map of Massachusetts coast with six sampling regions (hatch-marked) and territorial sea boundary (stippled).

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females, is analyzed separately and referred to as "marketable lobster". (In 1991, protection of V-notched female lobster was removed through legislative action thereby making them legal to harvest.) The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with cohort analysis (Pope 1972); detailed methods for cohort analysis are described in the cohort analysis section. Rates of exploitation were calculated with the equation $u=FA/Z$, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS AND DISCUSSION

Commercial Sea Sampling

During the period of May through November, 1991, eighty-seven sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 45,026 lobster was sampled from 16,366 trap hauls.

The 1991 coastwide mean catch per unit effort index (CTH'_3), 0.795 marketable lobster per trap, was 3.8% lower than the 1990 index, 0.826 (Appendix Table 1). Total Massachusetts commercial landings, 16,017,753 lbs, decreased by 4.2% from 1990. Landings from territorial waters, (10,987,368 lbs), decreased by 10.7. Landings and catch rate trends are depicted in Figure 2. The catch rates of sublegal lobster decreased significantly between 1990 and 1991 (Appendix Tables 2 and 3).

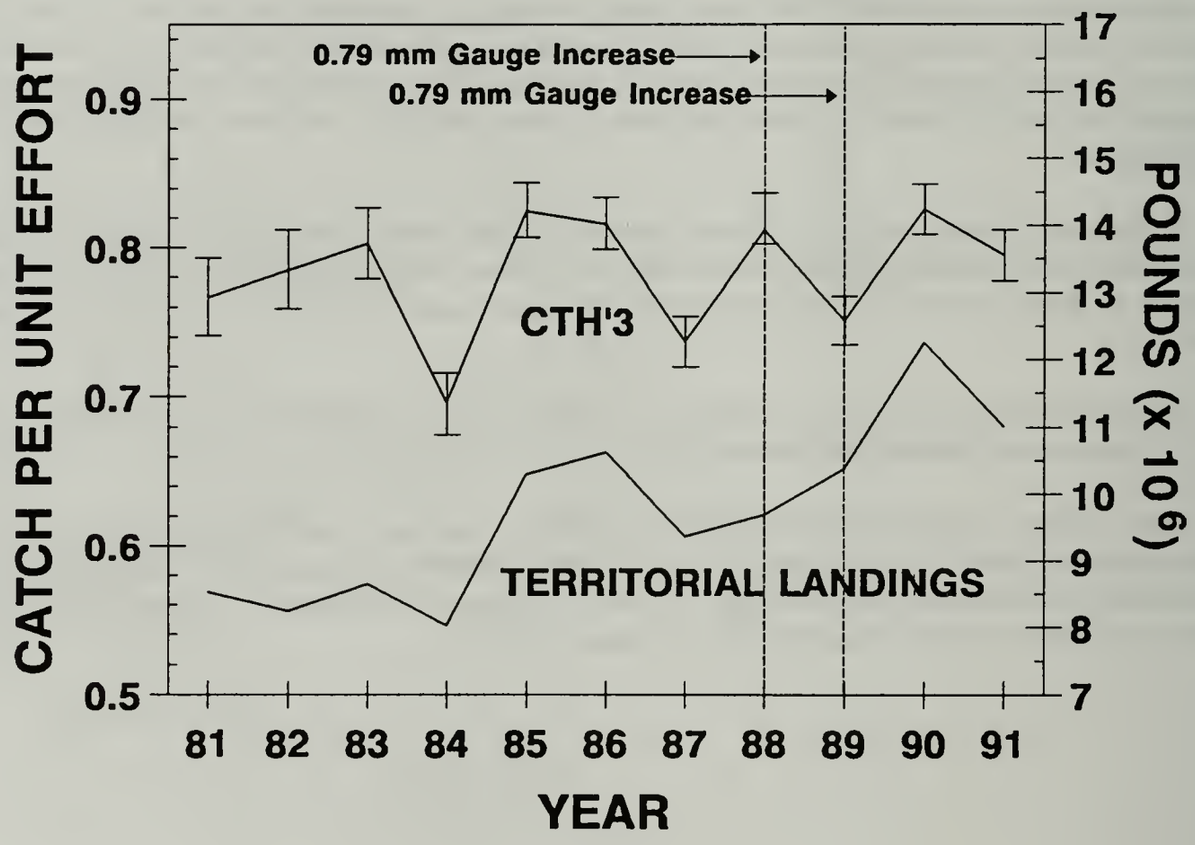

Figure 2. Catch per unit effort of marketable American lobster from commercial lobster trap sampling and Massachusetts lobster landings from territorial waters, 1981-1991.

Of all females sampled during 1991, 9.8% were ovigerous compared to 10.9% in 1990 (Appendix Table 4). A significant difference was observed between years ($P < 0.0001$). Trends in abundance of ovigerous females are depicted in Figure 3 (Appendix Tables 4-6).

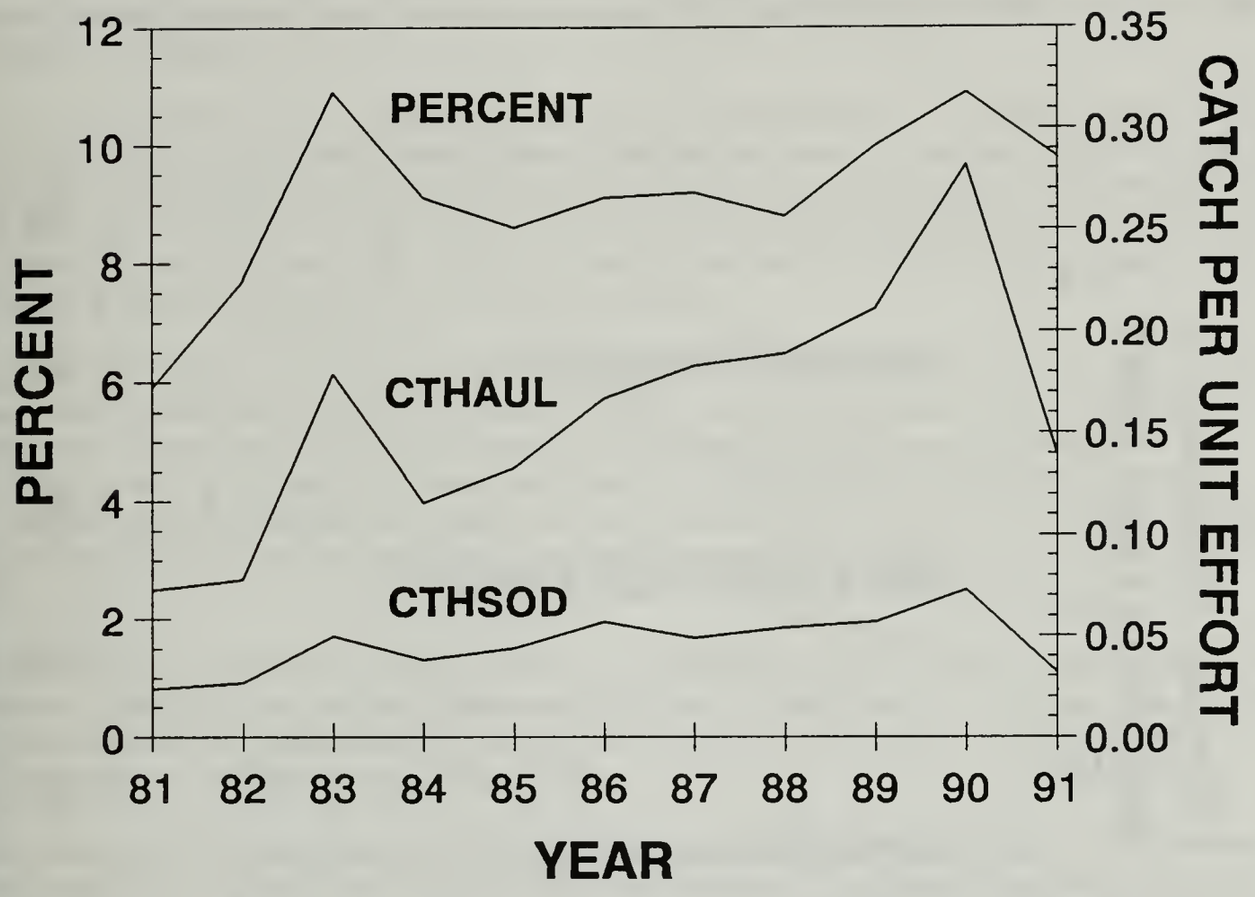

Figure 3. Relative abundance of ovigerous female American lobster in percent of total females and catch per unit effort, Massachusetts coastal waters, 1981-1991.

Approximately 94% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits (83 mm-94 mm CL), i.e., lobster which recruited to the legal size range during their most recent molt (Appendix Table 7). This index of the effect of fishing pressure on the size frequency was 92% in 1990. The index fluctuated from 59% to 54% between the two years for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) increased significantly from 1990 data. Indices for inshore Gulf of Maine regions (Z = 1.77-3.49, A = 83%-97%) and Buzzards Bay (Z = 3.08-3.50, A = 95%-97%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.71-0.77, A = 51%-54%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.59 off outer Cape Cod to 2.34 in Buzzards Bay (Appendix Table 9). The results of an investigation on methods for estimating F are included in a following section. Most regional estimates increased from those observed the previous year. Exploitation rates (u), i.e. the fraction of the population that is removed by fishing, were similar to 1990 data (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased

through 1987. Thereafter carapace length increases of 0.7 mm occurred in 1988 (88.2 mm) and 1989 (88.9 mm, Appendix Table 11) which probably reflected the similar numerical change in the minimum legal size during those years. Fishing mortality and exploitation rates appeared to stabilize accordingly. In 1991, fishing mortality increased while exploitation rate and mean carapace length exhibited minimal change.

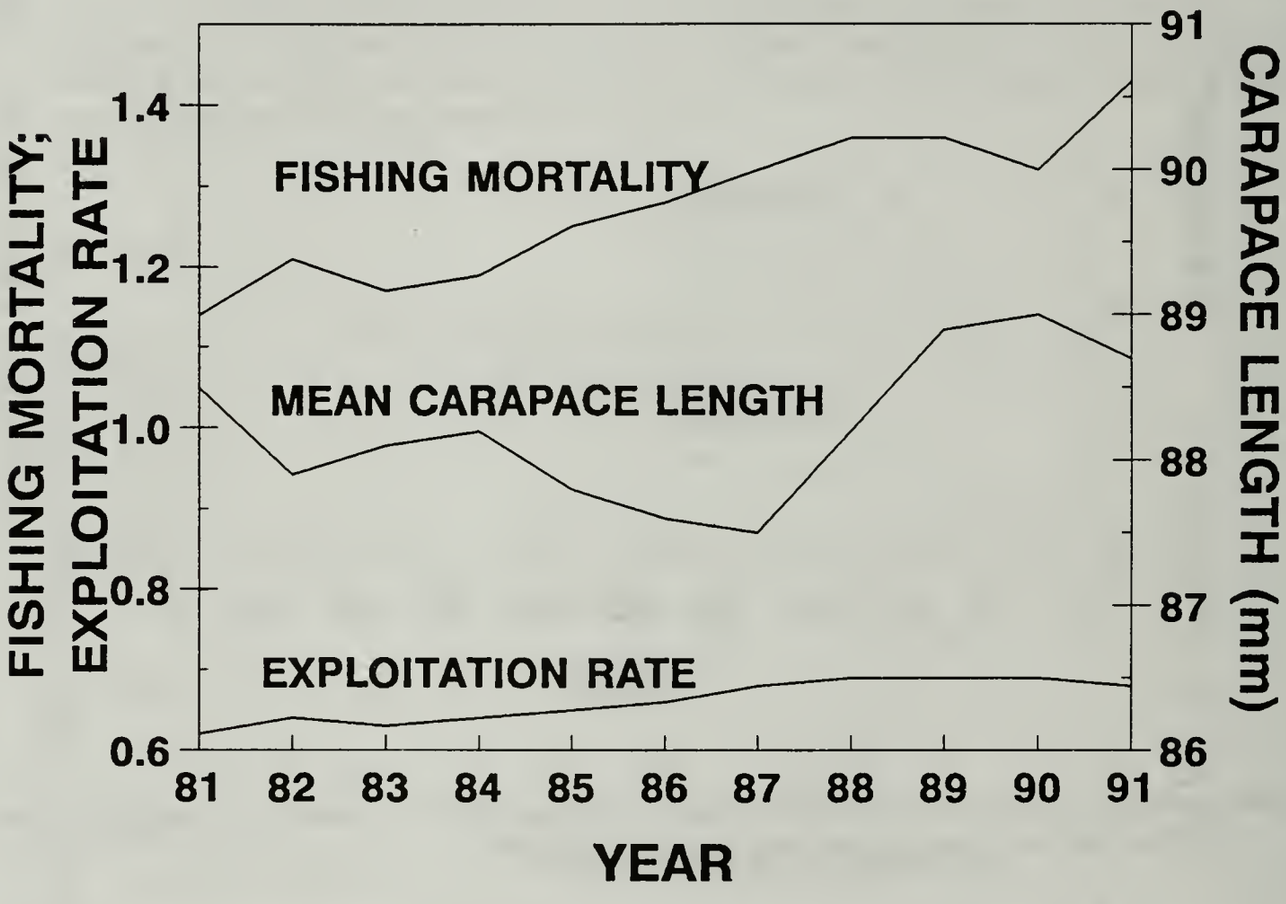

Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal waters, 1981-1991.

Sublegal sized lobster averaged 76.7 mm carapace length during 1991 compared to 77.6 mm during 1990 (Appendix Table 12). The mean size of all ovigerous females decreased from 88.0 mm in 1990 to 86.0 mm in 1991 ($P < 0.001$, Appendix Table 13).

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled declined from 18.6% in 1990 to 18.1% in 1991 (Appendix Table 14). The cull rates for legal and marketable size groups increased slightly while that for sublegal size groups was lower (Appendix Tables 15-17).

The coastwide incidence of lobster found dead in traps was 0.37%. This was consistent with the previous year's data (Appendix Table 18). However, the index for Buzzards Bay lobster was abnormally high

(1.74%), which is consistent with observations of unusual lobster mortality reported to us by other fishermen during September and October, 1991.

Gauge Increase Assessment

On 1 January, 1988 a five-year gauge increase program was initiated for American lobster. This change was promulgated by the New England Fishery Management Council in cooperation with the lobster-producing states in New England and the Mid-Atlantic. The minimum legal carapace length was raised from 81 mm (3 3/16") to 81.8 mm (3 7/32") in 1988 and to 82.6 mm (3 1/4") on 1 January, 1989. No increase in minimum legal size occurred during 1990. This program was suspended through legislative action prior to implementation of the remaining two 0.79 mm (1/32") increases.

One of the predicted benefits of raising the minimum legal size for American lobster was that growth overfishing would be alleviated by increasing yield per recruit. As the gauge increase program progressed during 1988 and 1989 the size frequency of lobster gradually adjusted to the new gauge dimensions via growth. A shift of the size frequency to larger sizes occurred (Figure 5). Only minor differences were observed between 1989 and 1991 size frequencies. The depression of the sublegal mode (80 mm) in 1991 is likely due to fishermen's early compliance with a regulated increase in minimum escape vent size to 1 7/8" x 6" in 1992.

A graphical analysis of 1986-1991 size frequency data, converted to market weight categories, shows the improvement in 1988-1989 data. A slight decline in the "chicken" category occurred in conjunction with an increased proportion of 1¼ - 1½ lb. and 1½- 3 lb lobster (Figure 6). The relative size of these market categories appeared to stabilize between 1989 and 1991.

An assessment of changes in the size structure of egg-bearing females was made with catch rates by 10 mm size groups for the years 1986-1991 (Figure 7). An increase in the relative abundance of ovigerous females was apparent in many 1990 size categories. Since the annual proportion of egg-bearing females to all females increased by only 1% (from 10.0% to 10.9%), the increase in catch rates of eggers was likely caused by the overall increase in lobster abundance. Likewise, a significant decline occurred in the catch rates of all size groups of eggers in 1991 which coincided with a 1.1% difference (from 10.9% to 9.8%) in the proportion of all females which were ovigerous.

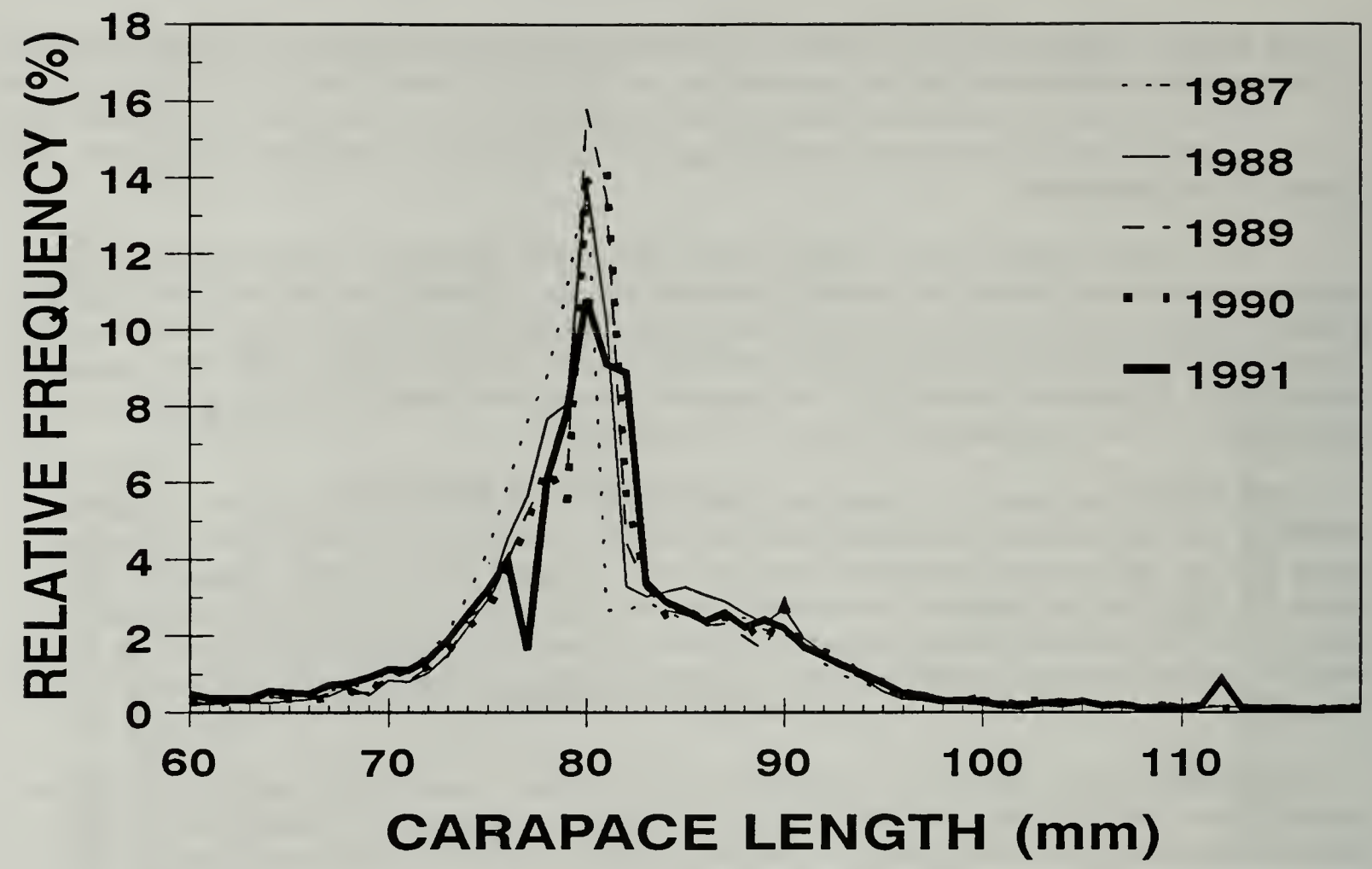

Figure 5. American lobster carapace length frequency from commercial lobster trap sampling, Massachusetts coastal waters, 1987-1991.

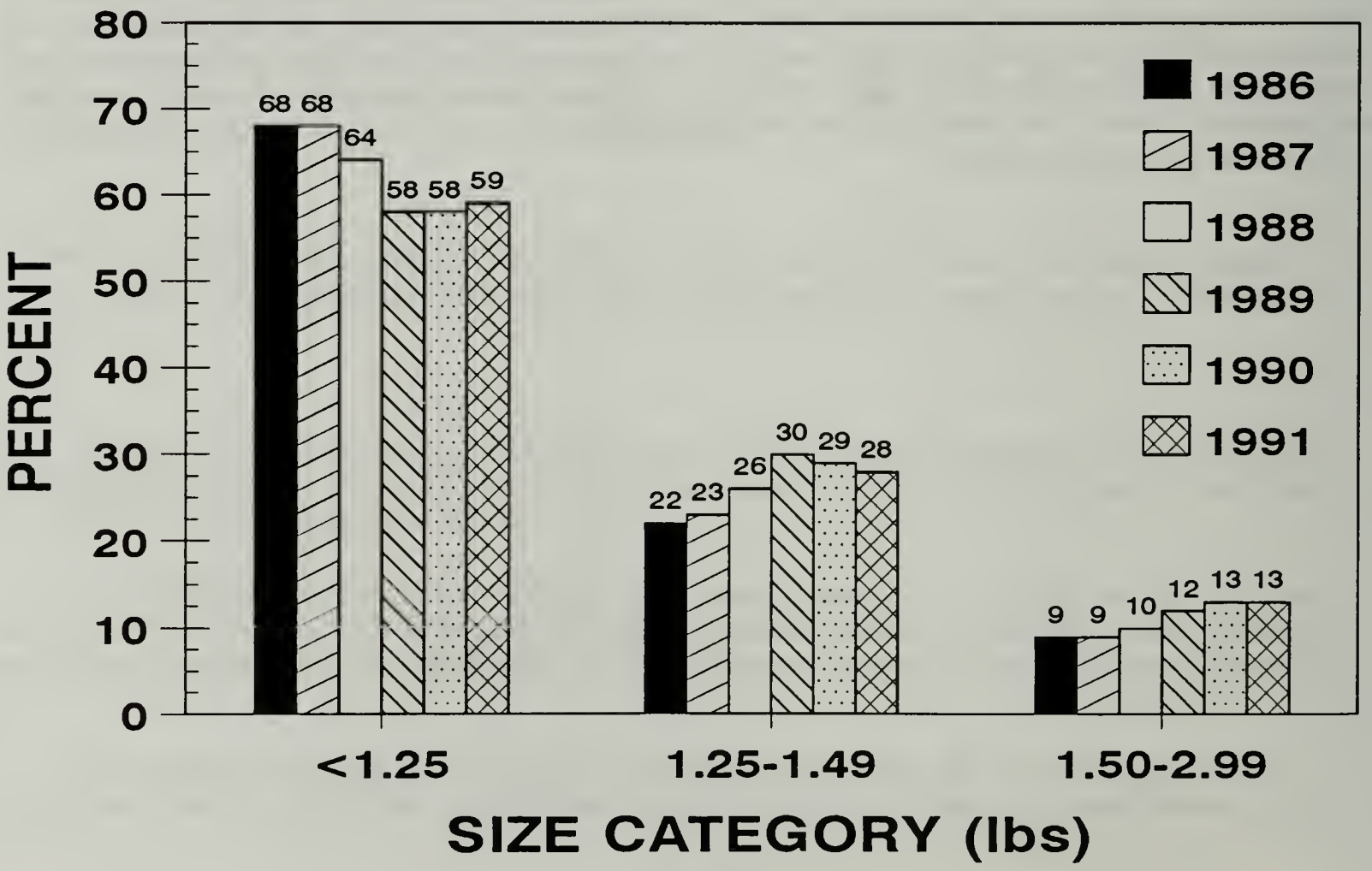

Figure 6. Percent of marketable lobster by market weight categories from commercial lobster trap sampling, Massachusetts coastal waters, 1986-1991.

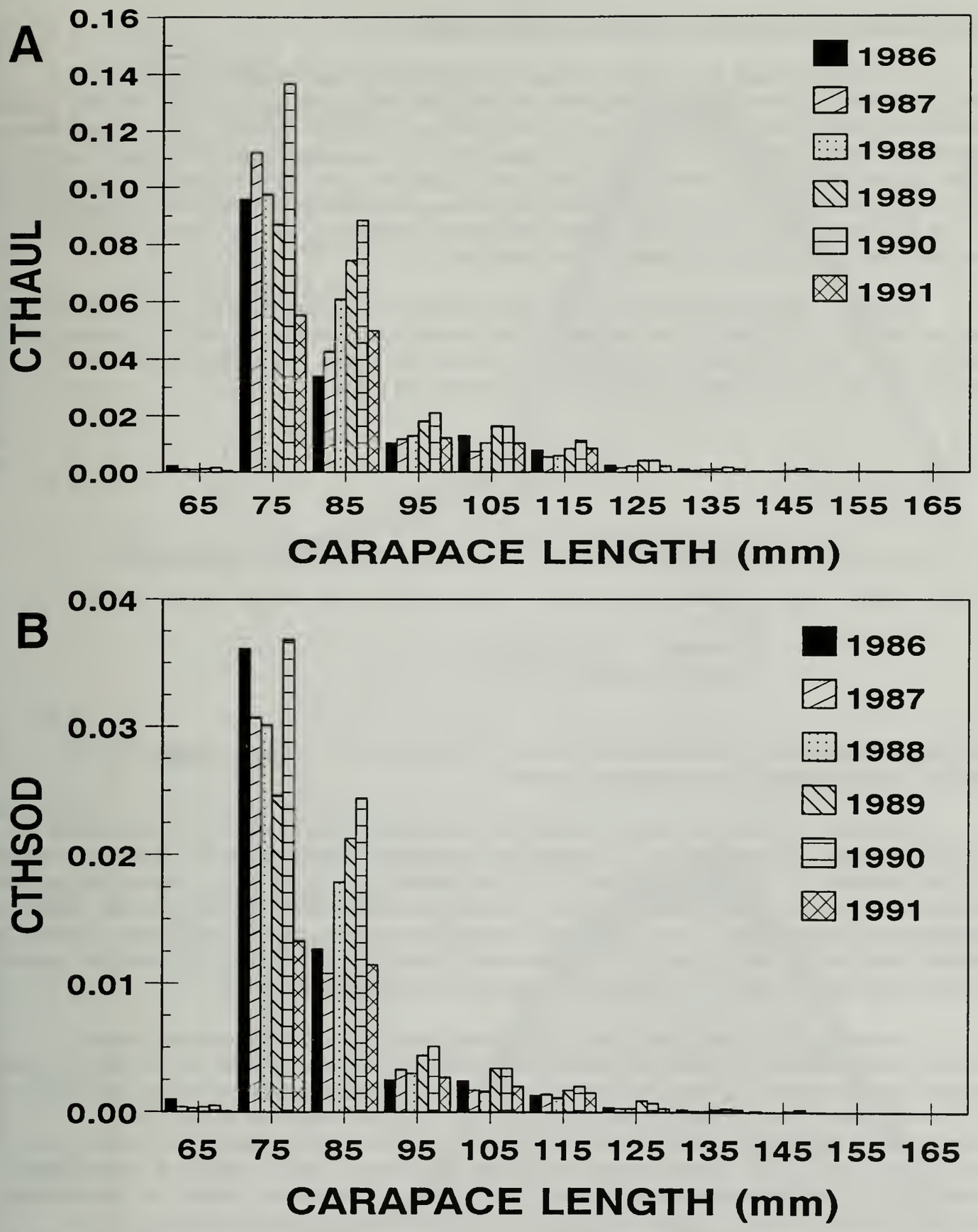

Figure 7. Catch per trap haul (A) and catch per trap haul set-over-day (B) of ovigerous female American lobster by 10 mm size groups, from commercial lobster trap sampling, Massachusetts coastal waters, 1986-1991.

Cohort Analyses of Sea Sampling Data Expanded to Landings

As previously noted, the routine procedure to account for regional and seasonal differences in annual or statewide parameters was to weight the monthly data within each region equally and each regional estimate by its area in sq.n mi. However, at the March 1992 meeting of the Atlantic States Marine Fisheries Commission lobster scientific work group, it was determined that a standard approach to estimating F by cohort analysis should include expansion of sample size frequencies according to seasonal and regional trends in landings. Such an approach allows parameter estimation and interpretation on the basis of population size. It was also concluded that separate analyses should be performed for each sex for regions where respective von Bertalanffy growth parameters are available.

Weights of marketable lobster measured during 1981-1991 commercial sea sampling were derived using weight/length equations for each region and sex and adjusted for culls as reported by Estrella and Cadrin (1991). Sample weights were totalled by year, month, and region. Sea sampling records were expanded to inshore landings by applying the following weighting factor:

$$W_{ijk} = \frac{L_{ijk}}{S_{ijk}}$$

where W = weighting factor
i = month
j = region
k = year
L = landings
S = predicted sample weight

(e.g. the weighting factor for an observation in Boston Harbor May 1981 = Boston Harbor May 1981 landings / sample weight in Boston Harbor May 1981).

Massachusetts lobster landings are compiled from fishermen's catch reports, in which landings are recorded by month and statistical area. Landings from appropriate statistical areas were pooled to coincide with the boundaries of sea sampling regions. Due to the absence of biological data for winter, landings in December and January were pooled with November landings to weight November biological data. Similarly, landings from February to April were pooled with May landings to weight May biological data. Monthly landings from June to October were used to weight monthly biological data directly. Seasonal and regional trends in territorial landings for 1990 and 1991 are presented in Figure 8.

Previous to 1990, monthly and areal landings breakdowns were recorded separately on each fisherman's catch reports (i.e. requested monthly breakdowns were not area specific, and vice versa). These separate breakdowns were used to approximate combined breakdowns by month and area for each year in the 1981-1989 time series (e.g. proportion of total annual landings in Boston Harbor May 1981). Comparisons of approximated and actual crosstabulations for 1990 showed systematic errors in the former (illustrated in Figures 9-11). Actual seasonal proportions are plotted by region in Figure 9. The separate seasonal (Figure 10A) and regional breakdowns (Figure 10B) were combined to produce the approximated crossbreakdown (Figure 10C); note that the seasonal statewide relative proportions (Figure 10A) are reflected in each region's seasonal profile and the annual regional proportions (Figure 10B) are depicted for each month. The difference between the actual proportions (Figure 9) and approximated proportions (Figure 10C) are plotted in Figure 11. Apparently, the generalization of applying state-wide and annual trends produced systematic errors (e.g. using a statewide seasonal trend is not appropriate to describe Buzzards Bay landings).

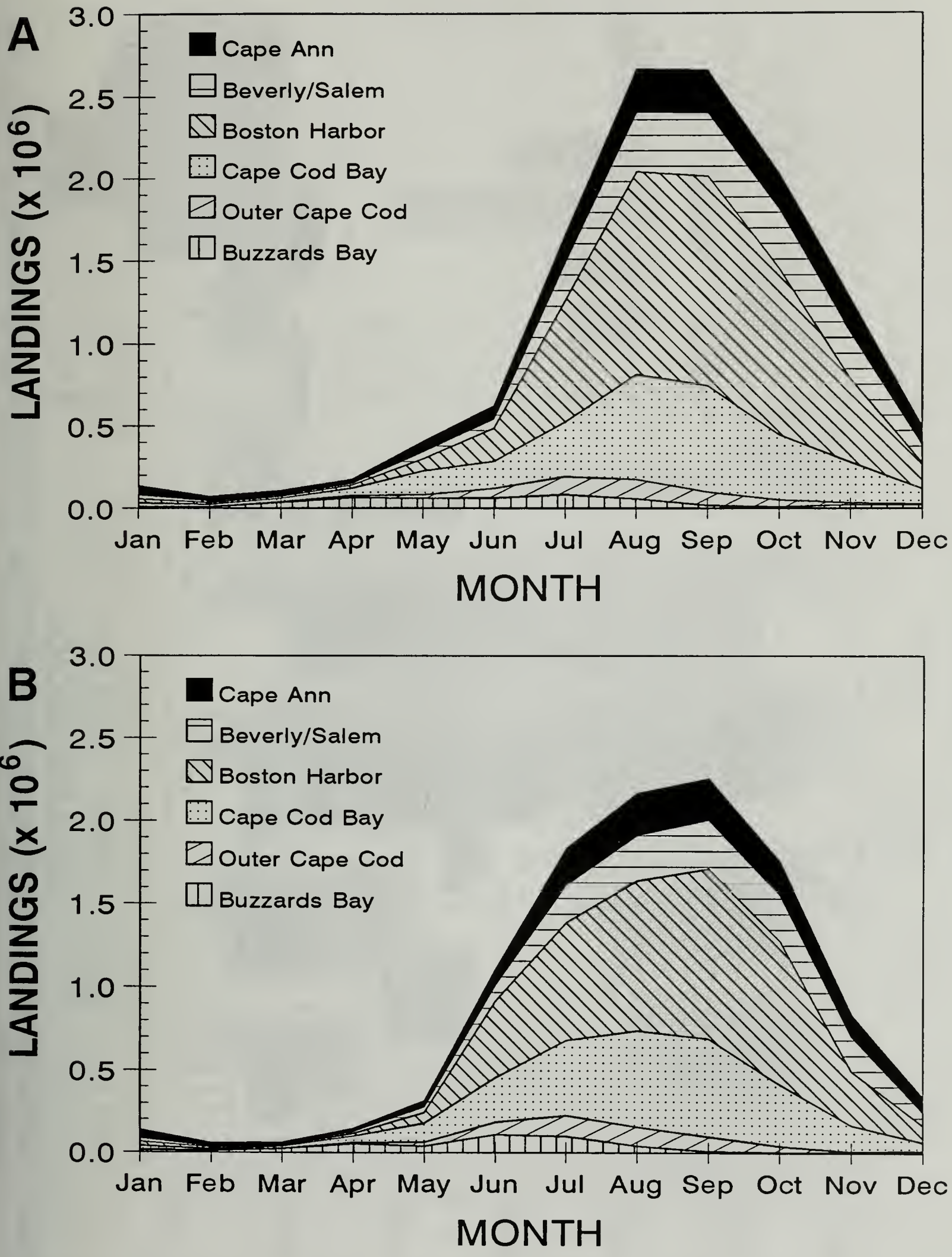

Figure 8. Reported lobster landings from Massachusetts territorial waters, 1990 (A) and 1991(B).

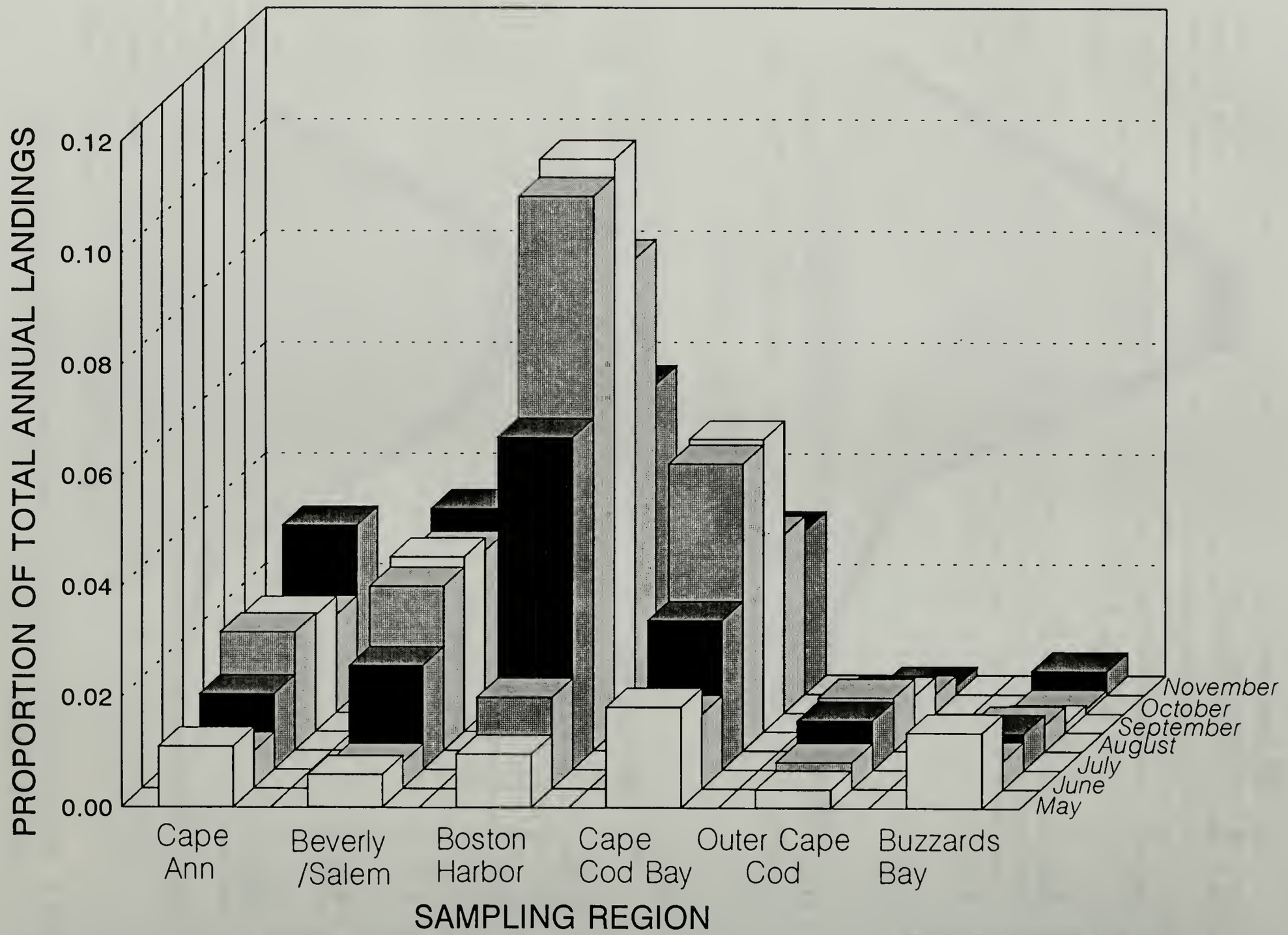

Figure 9. Regional and seasonal cross-breakdown of lobster landings from Massachusetts territorial waters, 1990.

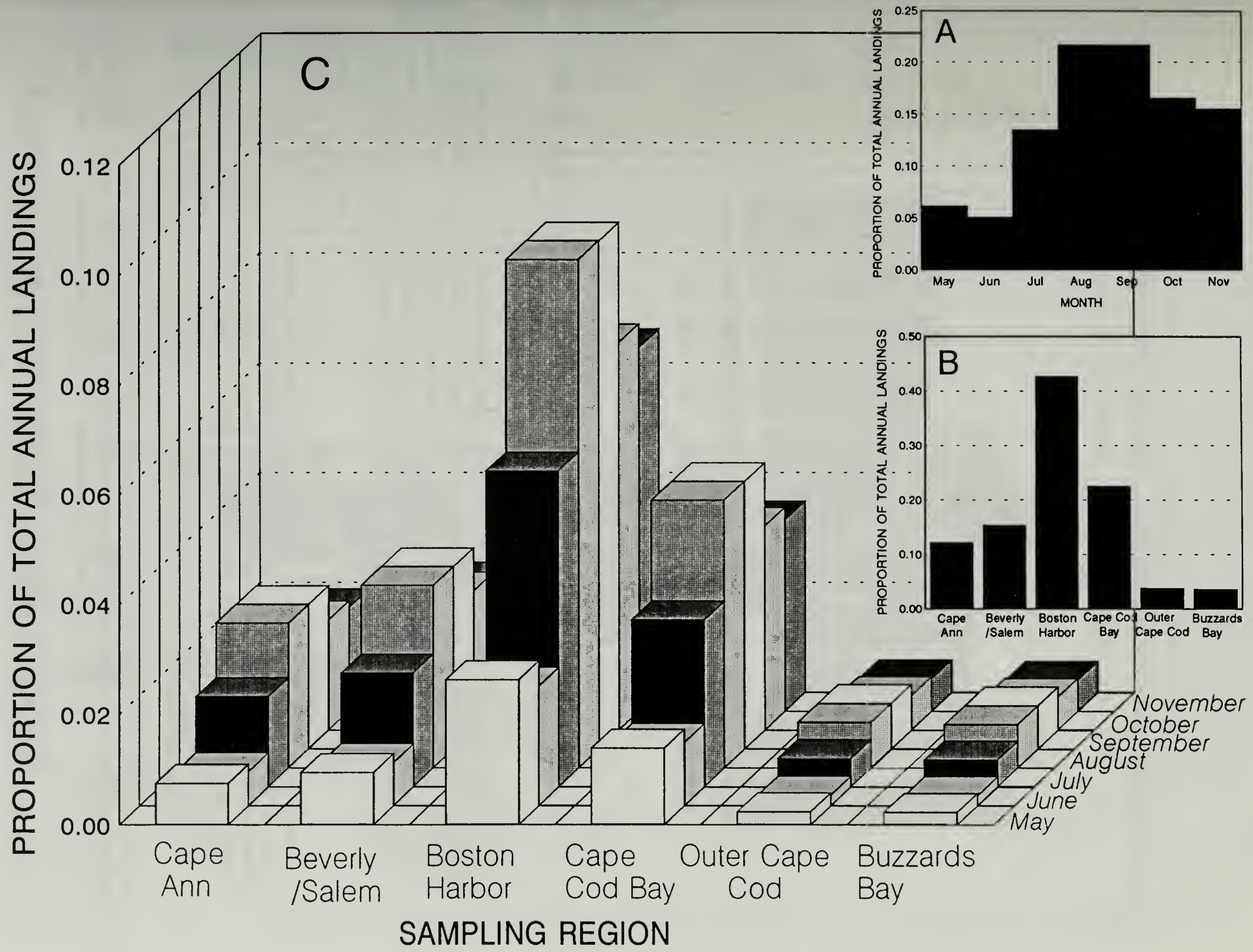

Figure 10. Coastal Massachusetts 1990 lobster landings, by month (A), region (B) and approximated cross-breakdown (C).

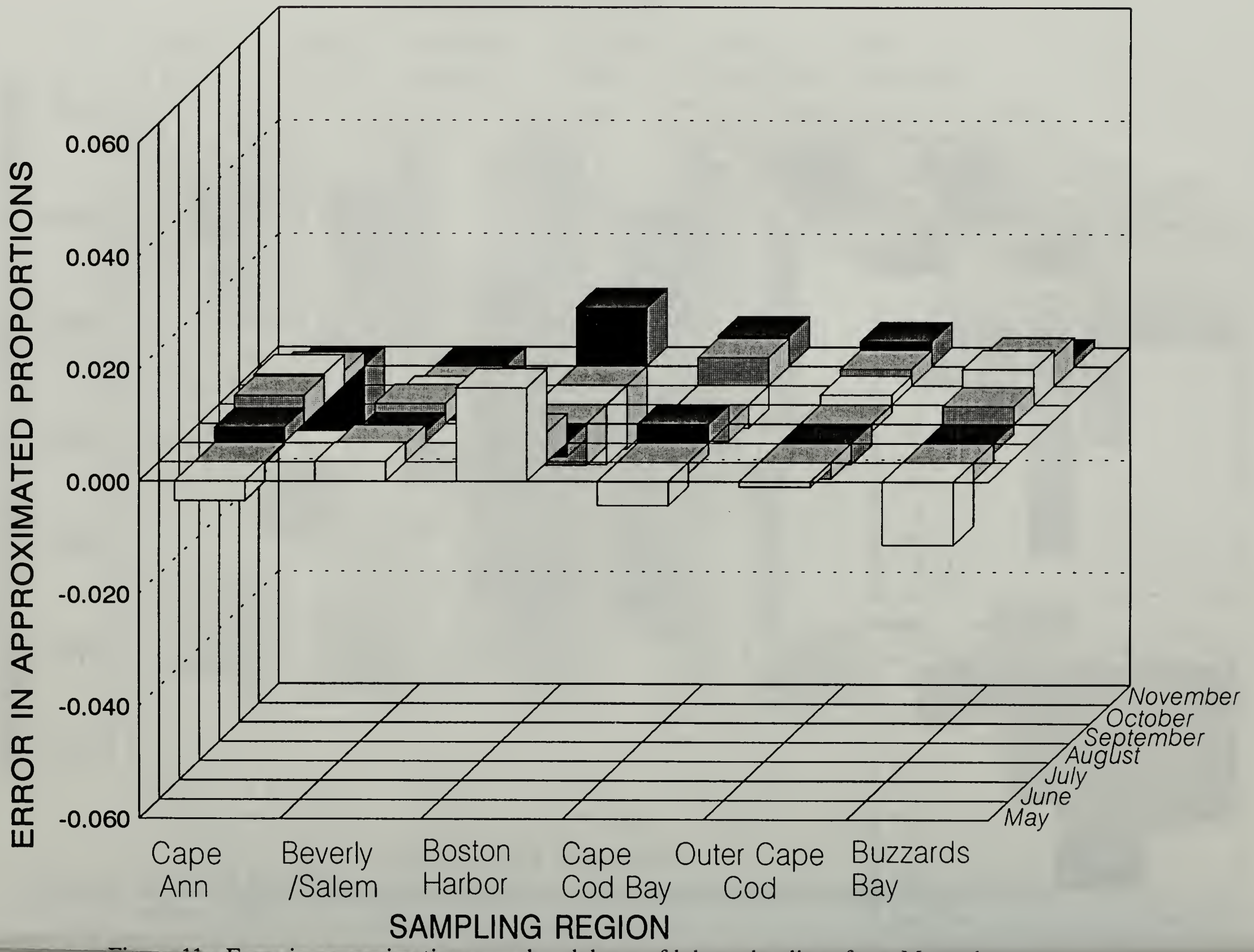

Figure 11. Errors in approximating cross-breakdown of lobster landings from Massachusetts

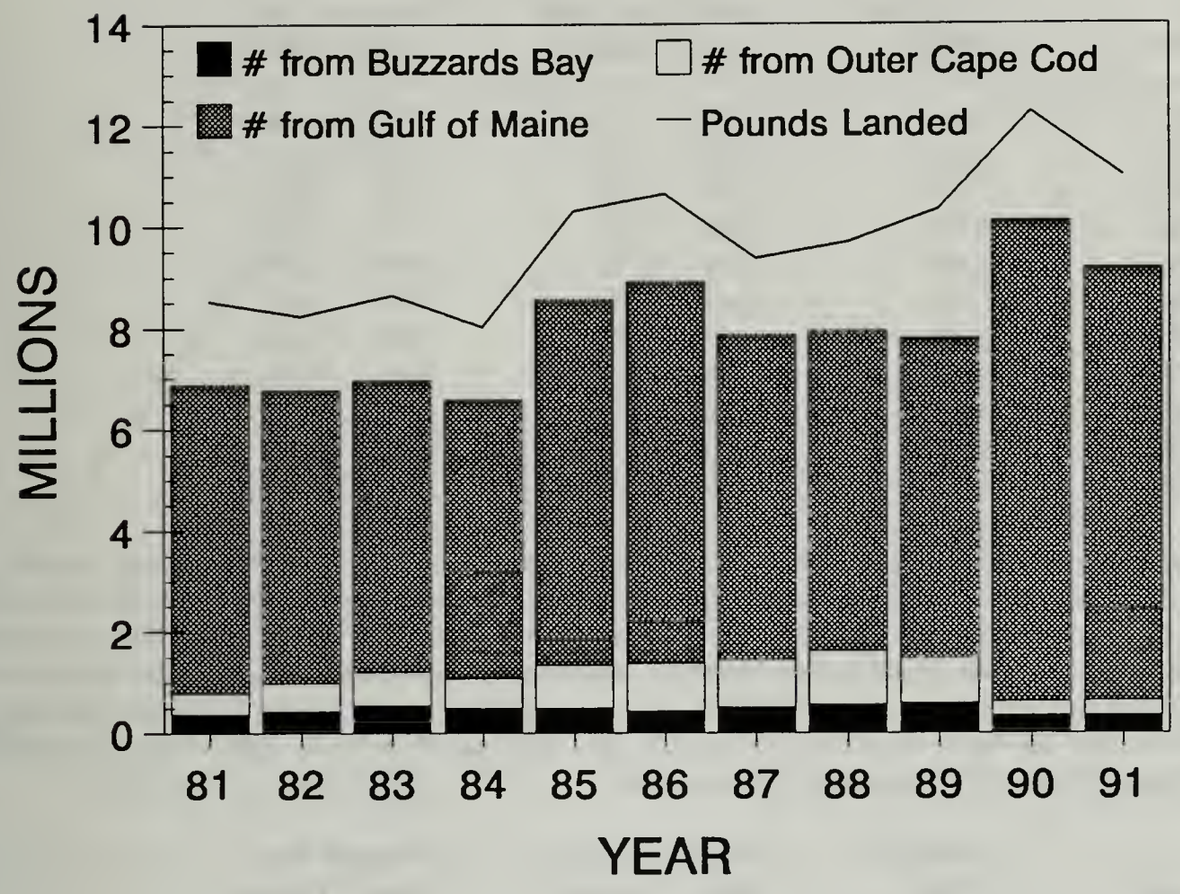

Figure 12. Reported lobster landings from Massachusetts territorial waters 1981-1991 in weight and number using fishermen's reports and expanded sea sampling data.

Analyses were performed on three general regions: Southern Gulf of Maine (composed of Cape Ann, Beverly/Salem, Boston Harbor, and Cape Cod Bay), outer Cape Cod, and Buzzards Bay. Regional landings are plotted in Figure 12; note that there was a change in statistical area delineations in 1990. Expanded carapace length frequencies were grouped into 5 mm classes by year, region, and sex. Cohort analysis (Jones 1974) was performed using the following regional von Bertalanffy parameter estimates:

Maximum CL(mm)	Growth Rate	Sex	Region	Source
253	0.0634	Both	Gulf of Maine	Fair 1977
270	0.096	Male	Outer Cape Cod	Cooper and Uzmann 1977
240	0.074	Female	Outer Cape Cod	Cooper and Uzmann 1977
190	0.0936	Male	Buzzards Bay	Russell et al. 1978
185	0.0966	Female	Buzzards Bay	Russell et al. 1978

Z was calculated for each length frequency using Gulland's (1969) method by grouping carapace lengths into 15% molt groups for the Gulf of Maine and outer Cape Cod Regions and 14% molt groups for Buzzards Bay. A natural mortality (M) of 0.15 was assumed (Fair 1977).

Estimates of F by year and region are listed below (mortality estimates for the southern Gulf of Maine were calculated for combined sexes because separate growth parameters were unavailable):

YEAR	S. Gulf of Maine	Outer Cape Cod		Buzzards Bay	
		Males	Females	Males	Females
1981	1.449	1.175	0.609	2.242	2.204
1982	1.601	1.121	0.515	1.974	1.970
1983	1.559	0.893	0.576	1.826	1.715
1984	1.753	0.838	0.526	1.929	1.603
1985	1.692	0.949	0.572	1.990	1.837
1986	1.762	1.042	0.614	2.070	1.930
1987	1.790	1.272	0.691	1.995	1.860
1988	1.843	1.220	0.590	1.981	1.998
1989	1.889	1.080	0.539	1.766	1.842
1990	1.836	1.220	0.517	1.798	1.803
1991	1.912	1.360	0.555	2.332	2.072

The fourteenth Northeast Regional Stock Assessment Workshop, Stock Assessment Review Committee (SARC), hosted by the National Marine Fisheries Service (report in prep.), reviewed methods and results of length-based cohort analysis of American lobster data. The SARC noted that cohort analysis results from single years are questionable due to the steady-state assumption (i.e., recruitment is in equilibrium with mortality). In order to address annual variability in recruitment, frequency data from all years with the same minimum legal size (81 mm CL 1981-1987 and 83 mm CL 1989-1991) were pooled to derive a time series average F for each region and sex:

Years	S. Gulf of Maine	Outer Cape Cod		Buzzards Bay	
		Males	Females	Males	Females
1981-87	1.639	0.955	0.560	2.009	1.824
1989-91	1.875	1.129	0.646	1.877	1.856

The consistency of the single year and pooled year analyses suggests that the assumption of equilibrium recruitment is valid. As noted by the ASMFC lobster scientific committee, the steady-state assumption is also justified by the annual stability in size frequency and annual recruitment; variability in year class size may be dampened by overlapping year classes recruiting to the fishery simultaneously.

A general increasing trend in fishing mortality is apparent in the Gulf of Maine. Estimates for Buzzards Bay are very high. The rates for outer Cape Cod are typically low because they are based on a segment of the resource which is biased toward large offshore migrants.

The SARC questioned the suitability of applying Gulland's (1969) technique for estimating terminal Z, because it assumes a constant growth increment and annual molt probability throughout the legal-size range and produces estimates of Z that are biased high. Sensitivity of cohort analysis to input parameters was subsequently assessed by multiple analysis of a single length frequency using a range of input parameters (Figure 13). According to the results, growth rate (K) has the strongest effect on the analysis, maximum size (L_∞) has moderate effect and M and Z have relatively little effect on the estimates of F. Therefore, the use of Gulland's technique has a negligible effect on cohort analysis. However, the large effects of growth parameters on F suggest that using the von Bertalanffy model, which describes continuous growth for the entire life history, may not be the most accurate model; an empirical discontinuous growth model based on molt increment and molt probability within the range of legal size may be more appropriate. Alternative growth models can be substituted into Pope's (1972) formula as described by Jones (1974).

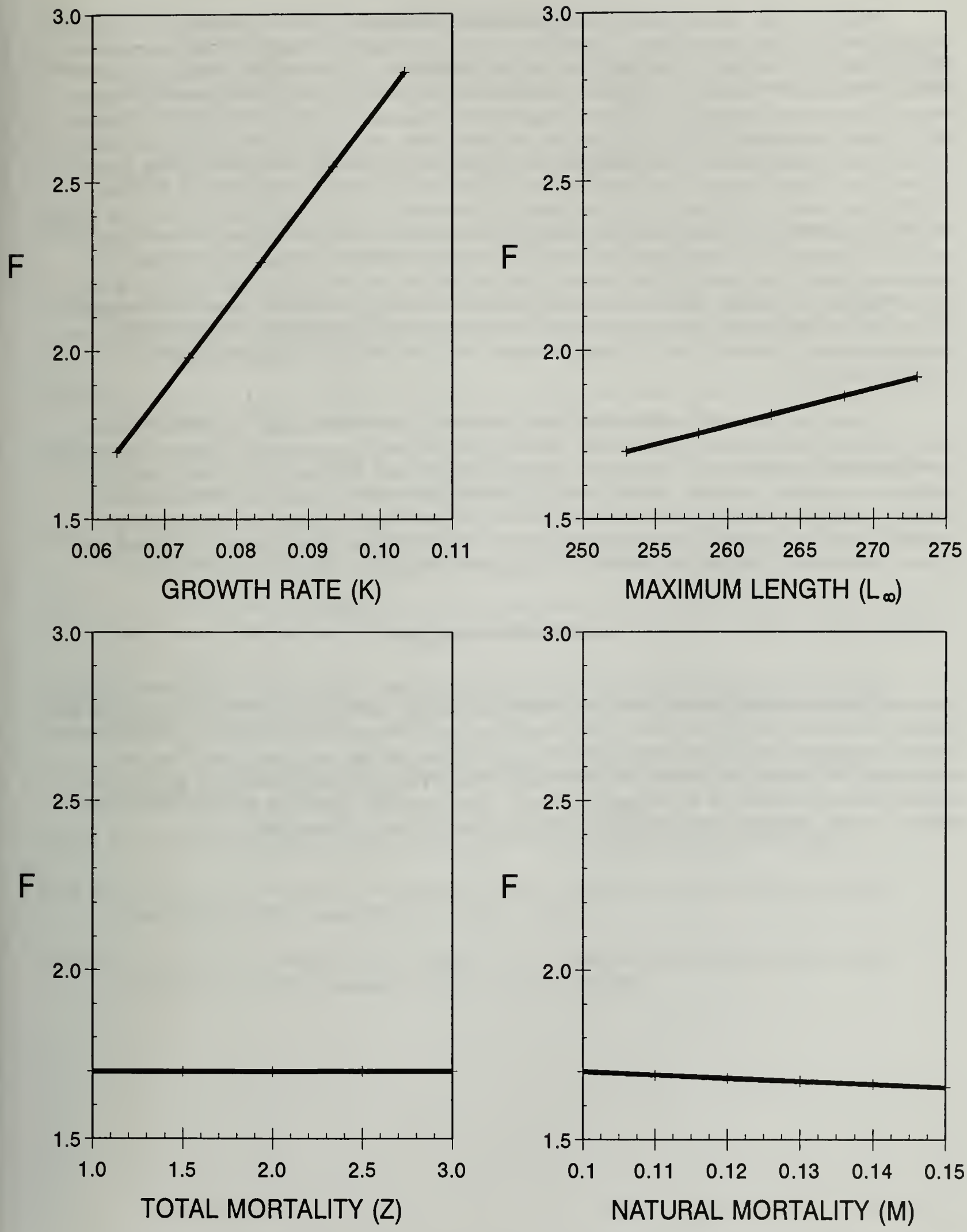

Figure 13. Sensitivity of cohort analysis to input parameters for estimating fishing mortality (F).

The SARC also noted that cohort analysis assumes that samples are representative of a unit stock. Analyses based on data collected from a smaller area may produce biased estimates because of movement between areas and resulting regional differences in size distribution. Cohort analysis of length frequencies sampled from inshore Massachusetts regions overestimates F for the composite stocks if there are larger lobster offshore or net movement is offshore. Therefore the estimates of F reported above for the inshore Gulf of Maine are probably higher than those for the entire stock. Although the Buzzards Bay estimates may similarly overestimate F for the southern New England stock, preliminary estimates of F for from offshore Rhode Island samples were higher than those using inshore data (T. Angell, RI Div. Fish and Wildlife, pers. comm.). The outer Cape Cod fishery is presumably a mixed-stock fishery as indicated by tag returns from northern and offshore Gulf of Maine as well as southern offshore canyons. However, the reported estimates of F for this region primarily characterize an offshore resource. Although size frequencies from offshore and mid-shelf areas can be sampled, the weighting of samples by regional and seasonal patterns in landings will under-represent the data because of the relatively small contribution of offshore landings relative to resource density. In order to represent an entire stock in cohort analysis, size frequencies must be sampled from all seasons and areas within the stock and weighted according to population density.

A point for consideration when using cohort analyses on unit stocks is that the proposed stocks (Gulf of Maine, Georges Bank/Offshore, and southern New England) are composed of regions characterized by different growth rates and are not amenable to single length-based analyses. Furthermore, since the preliminary overfishing definition is based on egg production per recruit, segments of stock units with different maturity or fecundity schedules should be adequately addressed. Therefore a prerequisite to modelling unit stocks should be the adequate definition of stocks whether they be based on population genetics, migrations, developmental parameters (e.g. growth and maturity), or harvesting strategies.

ACKNOWLEDGEMENTS

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APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.820	0.751	0.826	0.795
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904	0.868
Beverly-Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827	0.586
Boston Harbor	—	—	—	1.108	1.254	1.096	1.058	1.057	1.123	1.224	1.160
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630	0.693
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219	1.148
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598	0.575

Table 2. CTHSOD, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	0.580	0.672	0.718	0.521	0.647	0.700	0.578	0.509	0.695	0.716	0.665
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589	0.728
Beverly-Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408	0.324
Boston Harbor	—	—	—	0.901	1.162	1.138	1.156	0.639	0.966	1.103	0.924
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727	0.716
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078	0.077
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236	1.072

Table 3. CTHAUL, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	1.473	1.401	1.624	1.389	1.705	1.899	1.873	1.736	2.297	2.216	1.996
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782	1.783
Beverly-Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867	1.563
Boston Harbor	—	—	—	2.773	3.038	3.314	3.334	1.959	3.104	3.382	2.451
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921	2.086
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453	0.452
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994	3.181

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	10.0	10.9	9.8
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9	4.3
Beverly-Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8	3.2
Boston Harbor	—	—	—	1.4	1.2	2.0	1.7	2.0	2.1	2.7	2.8
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3	5.4
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5	18.3
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0	28.2

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	0.024	0.027	0.050	0.038	0.044	0.057	0.049	0.054	0.057	0.073	0.032
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035	0.024
Beverly-Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005	0.008
Boston Harbor	—	—	—	0.009	0.007	0.015	0.012	0.012	0.010	0.028	0.017
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017	0.028
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055	0.038
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349	0.073

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	0.073	0.078	0.179	0.116	0.133	0.167	0.183	0.189	0.211	0.282	0.140
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109	0.056
Beverly–Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023	0.049
Boston Harbor	—	—	—	0.030	0.025	0.050	0.037	0.038	0.043	0.075	0.064
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055	0.091
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342	0.251
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291	0.359

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	86	87	86	86	88	88	89	90	88	87	89
Cape Ann	91	92	87	89	87	87	88	90	84	81	90
Beverly–Salem	89	92	94	88	96	96	97	98	96	95	97
Boston Harbor	—	—	—	93	94	96	96	96	96	95	96
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93	91
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50	54
Buzzards Bay	98	96	96	94	96	97	97	97	95	94	95

Table 8A. Total instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	1.58 *	1.7	1.66	1.66	1.76	1.80	1.90	1.86	1.80	1.76	1.90
	79% **	82	81%	81%	83%	84%	85%	84%	83%	83%	85%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39	1.97
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%	86%
Beverly–Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81	3.49
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%	97%
Boston Harbor	—	—	—	2.52	3.59	2.60	2.77	2.86	2.96	3.00	3.40
	—	—	—	92%	97%	93%	94%	94%	95%	95%	97%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46	2.33
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%	90%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63	0.77
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%	54%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60	3.50
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%	97%

Table 8B. Total instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	1.35 *	1.4	1.39	1.41	1.47	1.49	1.54	1.56	1.53	1.50	1.73
	74% **	77	75%	76%	77%	78%	79%	79%	78%	78%	82%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66	1.77
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%	83%
Beverly–Salem	1.59	1.7	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83	2.29
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%	90%
Boston Harbor	—	—	—	1.82	1.75	1.92	1.88	1.84	1.94	1.87	2.19
	—	—	—	84%	83%	85%	85%	84%	86%	85%	89%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95	1.96
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%	86%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63	0.71
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%	51%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27	3.08
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%	95%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36	1.32	1.43
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04	1.50
Beverly–Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86	2.08
Boston Harbor	—	—	—	1.77	1.70	1.80	1.87	1.83	1.94	1.86	2.01
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72	1.66
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51	0.59
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97	2.34

Table 10. Estimated exploitation rate (μ), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69	0.69	0.68
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51	0.70
Beverly–Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85	0.82
Boston Harbor	—	—	—	0.82	0.81	0.80	0.84	0.84	0.86	0.85	0.82
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76	0.73
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38	0.42
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78	0.72

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9	89.0	88.7
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3	88.4
Beverly–Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3	87.5
Boston Harbor	—	—	—	86.8	86.9	86.4	86.6	87.5	88.0	88.1	87.8
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7	88.1
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1	95.3
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0	86.4

Table 12. Mean carapace length (mm), by state and region for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	75.8	76.3	76.2	76.1	76.3	76.1	76.1	76.3	77.5	77.6	76.7
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8	78.7
Beverly–Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1	73.4
Boston Harbor	—	—	—	77.1	76.9	76.9	76.5	75.6	76.8	77.4	75.4
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8	77.4
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8	78.8
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4	76.6

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	88.5	87.6	88.6	87.4	87.9	88.1	87.1	87.2	88.5	88.0	86.0
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1	91.7
Beverly–Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5	83.8
Boston Harbor	—	—	—	82.1	84.0	81.3	82.3	83.7	83.0	83.8	82.0
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0	83.9
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6	101.9
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8	79.8

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	10.0	10.8	10.7	14.8	18.1	20.9	17.0	18.2	19.2	18.6	18.1
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7	19.7
Beverly–Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3	28.9
Boston Harbor	—	—	—	13.3	19.3	19.1	16.9	16.3	13.8	14.7	13.5
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5	18.9
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5	13.2
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6	13.9

Table 15. Cull rate (percent), by state and region, for all legal–sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	8.1	9.7	9.2	12.7	14.8	17.0	14.7	15.7	14.9	15.4	15.6
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7	16.8
Beverly–Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6	22.8
Boston Harbor	—	—	—	10.1	16.2	15.8	12.9	13.1	9.9	9.9	12.3
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3	17.8
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1	12.8
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6	11.5

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	8.2	9.9	9.2	13.2	16.2	17.6	14.7	16.0	15.2	15.6	16.1
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2	16.8
Beverly–Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8	23.1
Boston Harbor	—	—	—	10.2	16.2	15.7	12.8	13.1	9.9	9.9	12.4
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2	17.8
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6	14.1
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4	11.7

Table 17. Cull rate (percent), by state and region, for sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1	20.2	19.2
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3	21.0
Beverly–Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2	31.6
Boston Harbor	—	—	—	14.5	20.5	20.0	18.0	18.0	15.2	16.4	13.9
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8	19.2
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7	14.3
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9	14.5

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1991.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12	0.17	0.37
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09	0.48
Beverly–Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29	0.41
Boston Harbor	—	—	—	0.00	0.03	0.03	0.23	0.09	0.03	0.04	0.01
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05	0.02
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62	0.35
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18	1.74

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